

Recent Development in Carbon-based Electrochemical Capacitors

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In the last several years, there has been significant progress in the development of eletrochemical capacitors using double-layer (carbon-based) electrode materials. These developments have resulted in both high performance devices being available for off-the-shelf purchase and the testing of proto-type laboratory devices that indicate good prospects for further improvements in performance of commercial devices in the relatively near future.

Material/Electrode Characteristics

The performance of electrochemical capacitors depends critically on the specific capacitance (F/gm and F/cm3) of the electrode material and the ionic conductivity of the electrolyte used in the device. The specific capacitance of a particular electrode material depends on whether the material is used in the positive or negative electrode of the device and whether the electrolyte is aqueous or organic. Most carbon materials exhibit higher specific capacitance in aqueous electrolytes. The specific capacitance can be derived from cyclic voltammetry and galvanometric testing of either single electrodes or assembled complete cells. As indicated in Table 1, the specific capacitance of carbon materials can vary widely from 75-250 F/gm and 70- 200 F/cm3 depending its surface area, pore size distribution, and the porosity (carbon loading). Electrodes from carbon material can be formed using either woven cloth or fibers or from coatings prepared using particulate carbon and a binder. The resistance of an electrode depends on the properties of the carbon, its thickness, the ionic conductivity of the electrolyte, and how the carbon layer is bonded to the current collector. The electrode resistance can be expressed in terms of its Ohm-cm2, which is essentially independent of the cross-sectional area of the electrode. Low resistance electrodes using aqueous electrolytes should have a specific resistance of about .05-.2 Ohm-cm2 and those using an organic electrolyte .5-2 Ohm-cm2.

Device Characteristics

The test data for devices using carbon show a wide range of cell characteristics in terms of energy density (Wh/kg), resistance, and power capacity (W/kg). As shown in Table 2, the energy density of commercial, large devices (capacitances up to 3500F) varies from 2-5 Wh/kg with the power capability of varying from 400 W/kg to 2000 W/kg for 90% efficient discharges. Large devices with RC time constants as low as .75 seconds are now available. Also shown in Table 2 are the characteristics of a small prototype device made using special carbons having specific capacitances of 100-120 F/gm in an organic electrolyte. The energy density of the small prototype device is more than twice that of the larger devices and its power density is nearly ten times higher. The characteristics of the various devices are compared graphically in Figure 1.

Reference: Burke, A.F., Ultracapacitors: Why, How, and Where is the Technology, *Journal of Power Sources* 91 (2000) 37-50, Nov. 2000

Table 1: Specific Capacitance of Carbon Electrode Materials

Material	Density gm/cm3	Electrolyte	F/gm	F/cm3
Carbon cloth	.35	KOH Organic	200 100	70 35
Carbon black	1.0	KOH	60-100	60-100
Aerogel carbon	.6	KOH Organic	160 60	96 36
SKT (1) Particulate carbon from SiC	.7	KOH Organic	185 100	130 70
SKT particulate carbon from TiC	.7	KOH Organic	300 120	210 84

(1) Nano-porous carbons produced from carbides by Skeleton Technologies

Table 2: Summary of the characteristics of advanced prototype and commercially available carbon-based ultracapacitors

Device	V	C (F)	R (mOhm)	RC (sec)	Wh/kg (1)
Skeleton Techn.R4*	3	47	5.2	.24	10.0
Maxwell	3	2700	.5	1.35	4.8
Ness	3	2650	.25	.65	5.1
Panasonic	3	1200	1.0	1.2	4.2
Montena	3	1800	1.0	1.8	5.6

*unpackaged
(1) Energy density based on $E=1/2CV^2$, $V_{rated}=3V$
Power based on $P=9/16*(1-EF)*V^2/R$, $EF=$ efficiency of discharge, $V=3V$

